

9.4 APPLICATIONS OF TAMDAR AIRCRAFT DATA REPORTS IN NWS FORECAST OFFICES

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1. INTRODUCTION

Weather data from 63 commuter aircraft were used by National Weather Service (NWS) meteorologists to make improved forecasts and warnings during an experiment called the TAMDAR Great Lakes Fleet Experiment. TAMDAR (Tropospheric Airborne Meteorological Data Report) is an instrument package and communications system designed by AirDat, LLC as part of NASA and FAA aviation safety initiatives.

Real-time weather data was collected during ascent, descent and cruise by an instrument with temperature, humidity, icing, and pressure sensors. Wind and turbulence data were calculated. TAMDAR data were transmitted via satellite to an AirDat ground station, and then relayed to NOAA's Earth Systems Research Laboratory (ESRL) where they were made available to certain government, university and airline meteorologists via an interactive web page and as data files. Data were also made available to the public via an AirDat maintained internet site. Further information about TAMDAR may be found in Daniels et al. (2006).

Meteorologists at many NWS Weather Forecast Offices (WFOs) in the central and eastern United States found TAMDAR data to be valuable in their forecasts and warnings. In addition, these data were also used by the NWS Storm Prediction Center in their severe thunderstorm monitoring and forecasting. Several examples are presented to demonstrate how TAMDAR was used by NWS WFOs in aviation, marine, and public weather forecasts.

2. THE GREAT LAKES FLEET EXPERIMENT

NASA contracted with AirDat LLC to design, build, and test an instrument to collect meteorological data from regional commercial aircraft. The resulting instrument (TAMDAR) was installed on 63 Mesaba Airlines Saab 340 aircraft flying over much of the central and eastern United States and Canada. Details on the development of the sensor can be found in Daniels et al. (2004).

A one year field evaluation of the data called the "Great Lakes Fleet Experiment" (GLFE) was conducted from 15 January 2005 to 15 January 2006. The purpose of the GLFE was to determine if data from regional aircraft could improve forecasts made by government, airline and military offices, and numerical models run by NOAA and AirDat. Further details about the development of TAMDAR and the GLFE can be found in Moninger et al. (2004).

The NWS produced a training presentation that was made available to WFOs in the GLFE area, and to other users upon request. A web page (<http://www.crh.noaa.gov/tamdard>) of flight schedules, reference documents, and other resources was also created in support of the GLFE.

3. DATA ACCESS

Meteorologists in NWS, airline meteorology, and military weather departments could access TAMDAR via the Aircraft Data Web hosted by ESRL (<http://amdar.noaa.gov>), or by a page hosted at AirDat (<http://www.airdat.com>). Some WFOs could also display TAMDAR on the Advanced Weather Interactive Processing System (AWIPS) via MADIS.

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4. DATA QUALITY

The quality of TAMDAR data have increased throughout the GLFE. Because the initial quality control program was not very robust, some poor quality soundings were made available without any flags to advise users of problems. AirDat has improved data quality during the GLFE by adding meteorologists to their staff, and by additional automated quality control programs. Quality control measures employed by Airdat are described by Anderson (2006).

Some data quality problems remain, despite the above mentioned efforts. One of the more significant problems is the loss of data when the aircraft is flying through areas of icing. The addition of heat to de-ice the unit renders some of the meteorological data erroneous during this time interval. These data are usually flagged and deleted from the soundings displayed on the ESRL web page. Figure 1 shows a sounding from Binghamton, New York, on 29 October 2005. The aircraft encountered icing a few minutes after takeoff. Notice the missing dewpoint and wind data while the heater was engaged.

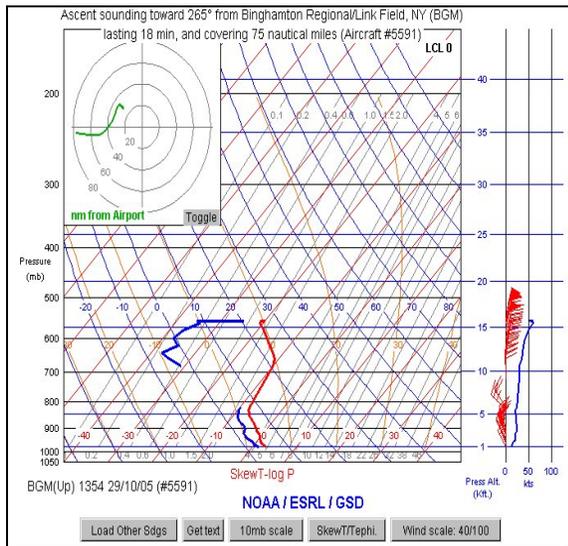


Fig. 1. Sounding from Binghamton, New York on 29 October 2005 shows missing data due to de-icing heater.

AirDat plans to develop an algorithm to account for this added heat, and preserve the meteorological data when the heater is on. Although missing or erroneous data is sometimes noted by forecasters in field offices, it seems to be infrequent, and not significant enough to affect their desire to use the data.

Figure 2 shows the results of an online survey conducted in August of 2005, showing that forecasters are satisfied with the quality of TAMDAR.

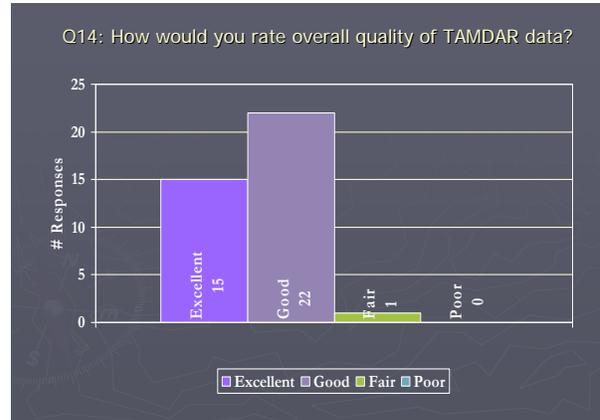


Fig. 2. Data quality question from survey of meteorologists conducted in August 2005.

4. METEOROLOGICAL APPLICATIONS

The availability of TAMDAR data in the central and eastern United States has been well received. One way this can be substantiated is by the number of visits to the ESRL Aircraft Data Web by meteorologists in the NWS Central Region. ESRL produces reports of web page visitors each month. For the six months prior to the start of the GLFE, Central Region WFOs averaged 120 visits to the aircraft data web each month. In the seven months after the start of the GLFE, average monthly visits increased to over 500 (Fig. 3).

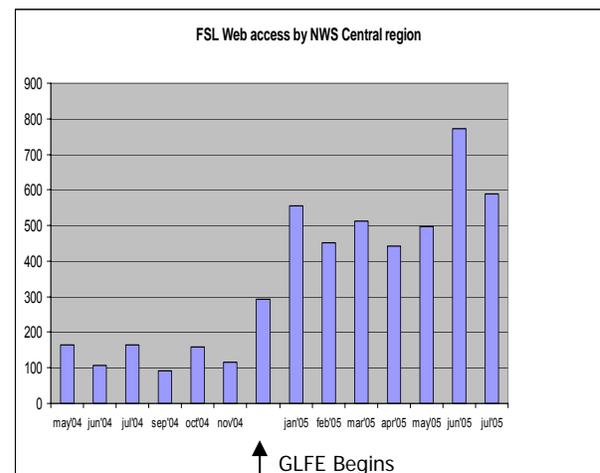


Fig. 3. Chart of NWS Central Region visits to the ESRL Aircraft Data Web.

In addition, the previously mentioned survey found that an overwhelming majority of the respondents said that TAMDAR helped them make improved forecasts and warnings (Fig. 4).

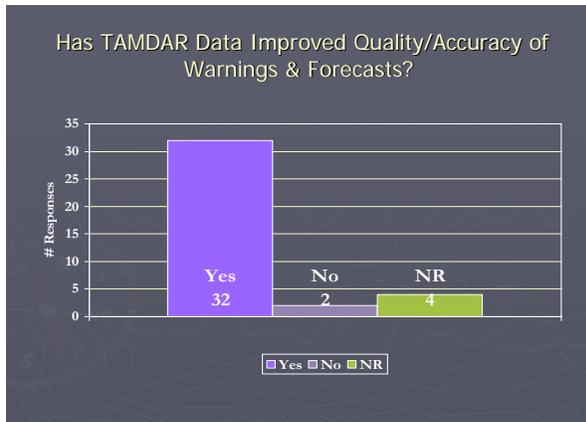


Fig.4. TAMDAR survey results.

This should not be surprising, as many WFOs in the GLFE area have no radiosondes in their forecast areas, are beyond the central U.S. Wind Profiler Network, and get infrequent GOES satellite soundings due to extensive cloud cover. The almost mesoscale availability of TAMDAR makes assessment of the atmospheric much more precise. This permits more accurate forecasts, and better situational awareness that can lead to improved warnings.

5.1 Model Verification

Effective use of numerical model output requires knowledge of past and current model performance. To do this, meteorologists often compare 3- and 6-hour model output to available upper air data. This is often difficult, as radiosonde data are only available at 12 hour intervals, wind profiler data is limited to the central United States, and GOES soundings are not produced if there is opaque cloud cover. Soundings from TAMDAR and other aircraft platforms allow for more frequent and accurate model verification and comparisons. The WFO in Grand Rapids, Michigan, compared TAMDAR to model output during the early morning hours of 17 March 2005. An excerpt from their Area Forecast Discussion follows:

AREA FORECAST DISCUSSION
NWS GRAND RAPIDS MI
AFDGRR 308 AM EST THU MAR 17 2005

GFS AND ETA MODEL SOUNDINGS LINE UP VERY NICELY WITH CURRENT **TAMDAR** SOUNDINGS AND SHOW A REMARKABLY SIMILAR PROFILE.

Favorable comparisons of model forecasts and current upper air data give meteorologists confidence in the model solution. Unfavorable comparisons are also useful, as they can alert meteorologists that the model may be producing a poor forecast. An example from the WFO in Grand Forks, North Dakota, shows how TAMDAR helped them discover why the model precipitation forecast was not going as planned. Their Area Forecast Discussion from 6 July 2005 follows:

AREA FORECAST DISCUSSION
NWS EASTERN ND/GRAND FORKS ND
AFDFGF 1117 AM CDT WED JUL 6 2005

RADAR TREND SHOWS PRECIPITATION IN SOUTHERN MANITOBA NOT MOVING INTO NORTHEAST ZONES THOUGH MODEL WANTS TO MOVE PRECIPITATION SOUTHEAST. **TAMDAR** SOUNDING OVER EASTERN ZONES INDICATE MODEL SOUNDINGS NOT HANDLING LOW LEVEL MOISTURE VERY WELL BELOW 800 HPA.

5.2 Marine Forecasting

Meteorologists at the NWS in Cleveland used TAMDAR data to forecast the development and inland penetration of a lake breeze from Lake Erie during the afternoon of 16 April 2005. An excerpt (below) from their Area Forecast Discussion issued at 1800 UTC, states that significant south winds will prevent the lake breeze from moving very far inland:

AREA FORECAST DISCUSSION
NWS CLEVELAND OH

TAMDAR DATA NEAR CLEVELAND WAS INDICATING THE WINDS FROM SOUTH AROUND 25 KNOTS AT 2,000 FEET. THE LAKE BREEZE, IF IT DOES DEVELOP, SHOULD BE RIGHT ALONG THE LAKESHORE FROM NEAR CLEVELAND THROUGH ERIE

A lake breeze did develop in the late afternoon, reaching the Cleveland Burke Lakefront airport around 2000 UTC, and Cleveland Hopkins airport (further inland) around 2300 UTC.

The development and movement of lake breezes is not only important to mariners, but also to lakeshore airports. Runway configurations are very sensitive to wind speed and direction. A large hub such as Chicago O'Hare may need as much as twenty minutes to "turn around" the airport, making an accurate forecast of lake breeze formation and arrival important to reduce delays. Efforts to use aircraft weather data to address this problem were begun in the late 1990s, when Iowa

State University and NWS Chicago researchers used aircraft data in a mesoscale numerical model to forecast lake breezes from Lake Michigan (Labas, 1999).

TAMDAR has also been used extensively by the NWS in Marquette, Michigan, in forecasting winds and waves for the Open Waters Forecast for Lake Superior. The availability of TAMDAR surrounding the lake in the United States and Canada has given them the ability to assess both the wind speed and stability of the atmosphere. Both are vital to the production of accurate wave height forecasts.

5.3 Temperature Forecasts

Prior to the availability of aircraft soundings, most meteorologists had to base their temperature forecasts on the 00 UTC and 12 UTC sounding from the nearest NWS radiosonde, or on a model forecast sounding. This method was hampered because radiosondes are sometimes hundreds of miles from WFOs, and that model soundings are not always accurate. TAMDAR soundings were available at a higher spatial and temporal density than radiosondes in the GLFE area. This helped meteorologists make improved temperature forecasts for their areas on many occasions.

An example from the WFO in Minneapolis, Minnesota on 4 February 2005 shows how upstream TAMDAR soundings at Sioux Falls, South Dakota showed the atmosphere to be warmer than expected and much warmer than the downstream Minneapolis sounding (see area forecast discussion below):

AREA FORECAST DISCUSSION
NWS TWIN CITIES/CHANHASSEN MN
AFDMPX 945 AM CST FRI FEB 4 2005

.DISCUSSION...JUST LOOKED AT 14Z **TAMDAR** SOUNDING OVER FSD. VERY WARM NOSE OF +15 C AT 902 MB. SOUNDING IS VERY DRY. GIVEN DOWNSLOPE OFF THE BUFFALO RIDGE...AND LACK OF SNOW COVER OVER SOUTHWESTERN CWA... EXPECTING SOME RECORD WARMTH WITH 60 DEGREE READINGS OVER SOUTHWESTERN CWA. HAVE BUMPED UP MAXES FOR TODAY MAINLY CENTRAL AND SOUTHWESTERN CWA.

Forecasters were confident enough to update their forecasts to include mention of record highs for the date. It was a good decision, as record highs were tied at Marshall and Pipestone (61F), and a new record high was established at Minneapolis (51F).

5.4 Wind Forecasting

The NWS in Grand Forks, North Dakota, used a combination of wind profiler and TAMDAR data in the decision to extend a Wind Advisory for eastern North Dakota during the late afternoon of 22 May 2005. A TAMDAR sounding from Grand Forks at 1847 UTC (Fig. 5) shows a nearly dry adiabatic temperature sounding from the surface to almost 750 mb. More importantly, winds to 50 knots (25 m s^{-1}) are reported just a few hundred feet above the ground (see highlighted wind barb).

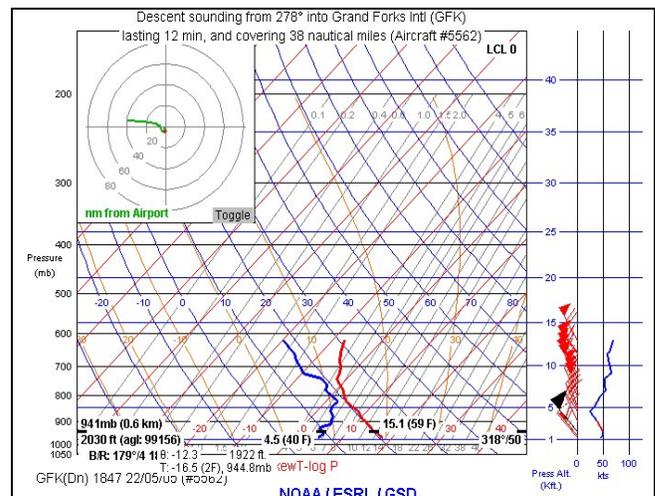


Fig. 5 TAMDAR sounding from Grand Forks, North Dakota on 22 May 2005.

The meteorologists referenced the TAMDAR soundings and wind profiler data in the following Area Forecast Discussion:

AREA FORECAST DISCUSSION
NWS EASTERN ND/GRAND FORKS ND
AFDFGF 400 PM CDT SUN MAY 22 2005

.FSL **AIRCRAFT** DATA INTO GFK AND GLACIAL RIDGE SHOW WE ARE FULLY MIXED TO 825 MB AND THE 40 KNOTS CONTAINED WITHIN THE BOUNDARY LAYER. SO EXTENDED THE WIND ADVISORY TO 7 PM.

5.5 Convective Forecasts

TAMDAR soundings were used extensively in the Northern Plains and Great Lakes to monitor moisture content and stability of the atmosphere during the GLFE. Many WFOs monitored TAMDAR soundings throughout the day to determine whether or not mid level capping inversions were strengthening or weakening.

The erosion of a mid level cap often was the determining factor as to whether convection developed or not. TAMDAR data was instrumental in the decision made by WFO Sioux Falls, South Dakota to lower the threat of thunderstorms and severe weather on 23 June 2005. A TAMDAR sounding from Aberdeen, South Dakota, at 1951UTC (Fig. 6) showed a significant capping inversion around 800 mb that would require surface temperatures of 104F to overcome.

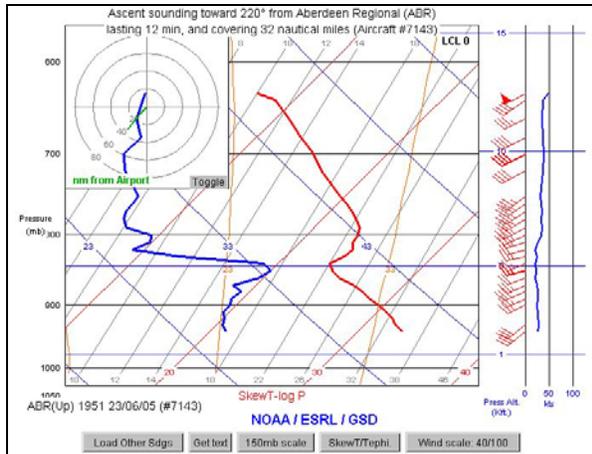


Fig. 6. Aberdeen, S.D. sounding from 1951 UTC 23 June 2005 showing strong capping inversion.

This was discussed in their area forecast discussion, an excerpt of which is presented below:

AREA FORECAST DISCUSSION
NWS SIOUX FALLS SD
315 PM CDT THU JUN 23 2005

.DISCUSSION... CONCERNS FOR THIS PACKAGE ARE MULTIPLE CHANCES FOR THUNDERSTORMS AND WITH EACH ONE WHETHER OR NOT THE CAP WILL SUPPRESS ACTIVITY. 19Z **TAMDAR** SOUNDING FROM ABR SHOWS CAP AROUND 800MB...WITH PLENTY MORE WARMING NEEDED TO BREAK THROUGH.

Many convective applications of TAMDAR are presented in great detail by Brusky and Kurimski (2006) and by Fischer (2006).

5.6 Aviation Forecasts

The availability of TAMDAR at many small and medium size airports in the central and eastern United States has allowed meteorologists to better forecast several different aviation weather hazards. Dense fog is one of these hazards, and often difficult to forecast. Many NWS

meteorologists now use a method to forecast dense fog developed by United Parcel Service Airlines. It usually delivers excellent results, but its success depends on the input of accurate moisture and stability information for the boundary layer. Many WFOs far from radiosondes use model soundings for this information. The recent availability of TAMDAR allows meteorologists to use observed stability and moisture measures, instead of model forecasts. This usually results in a better forecast.

The WFO in Detroit found TAMDAR to be useful in forecasting a dense fog event on the evening of 4 February 2005. Figure 7 depicts a sounding from Detroit Metro airport at 2122 UTC, showing moisture increasing with height (circled area) and a low level inversion. The Detroit WFO issued a

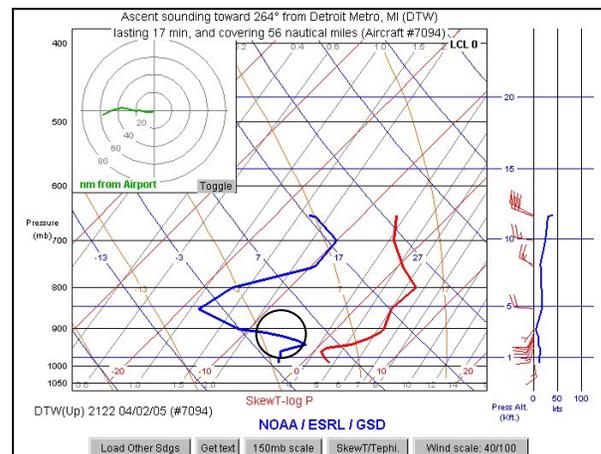


Fig. 7. TAMDAR sounding from Detroit at 2122 UTC 4 February 2005.

terminal forecast calling for visibilities to fall to ½ mile after 0600 UTC, and to linger into the following morning. Surface observations shown below indicate that visibilities dropped to as low as a ¼ mile, with Runway Visual Ranges below minimums for many aircraft.

Surface Observations from Detroit

KDTW 0532Z 0000KT **2SM BR** CLR
KDTW 0739Z 17003KT **1 3/4SM BR** R04/1000V3500
KDTW 0936Z 17004KT **1/4SM FG** R04/0500V0600
KDTW 1154Z 16004KT **1/4SM FG** R04/0600V0800

The ability to determine real time moisture and winds in the boundary layer is one of the most valuable benefits of TAMDAR. This permits better forecasting of cloud bases, tops, and dense fog.

TAMDAR can also be useful in determining the presence of low level wind shear (LLWS). Aircraft ascending or descending in the vicinity of an

airport are in an ideal location for depicting low level wind shear. An example of this use was by the WFO in Green Bay, Wisconsin, on the evening of 29 October 2005. LLWS was forecast to begin after 0600 UTC in the Terminal Forecasts (TAF) that night. TAMDAR soundings from around 0120 UTC showed that LLWS was already present (Fig. 8).

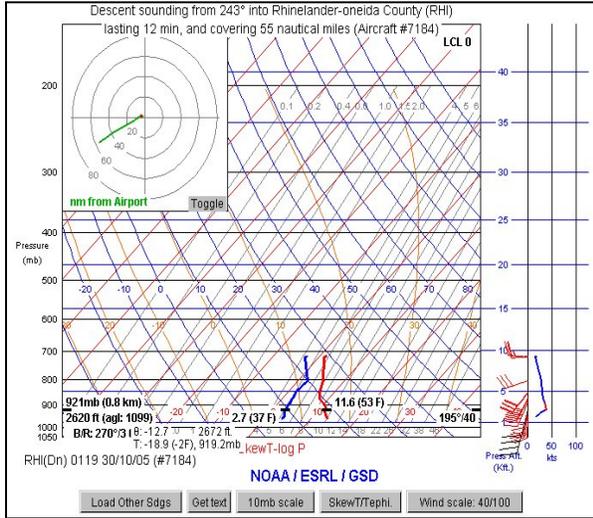


Fig. 8. TAMDAR sounding from Rhinelander, Wisconsin showing 40 kt (20 m s^{-1}) winds at 1,099 ft AGL.

The meteorologist was able to update the TAF and begin the LLWS more than 3 hours earlier than the prior forecast. This was mentioned in the Area Forecast Discussion that was issued around 0245 UTC:

AREA FORECAST DISCUSSION
 NATIONAL WEATHER SERVICE GREEN BAY WI
 945 PM CDT SAT OCT 29 2005

TAMDAR SOUNDINGS AT RHI... SAW...EAU...LSE AND CWA SHOW 35-40KTS OF WIND AT 1000' AGL...SO WILL UPDATE TAFS IN OUR CWA TO START LLWS QUICKER.

5.7 Miscellaneous Applications

Many WFOs find TAMDAR data useful in updating the environmental wind and temperature table used in their WSR-88D radars. The radar software requires users to input a “first guess” wind field to assist the radar in calculating wind speed and direction from the radar radial velocities. The software also needs the heights of the freezing level and $-20 \text{ }^\circ\text{C}$ level. These are used in several hail and precipitation estimation

algorithms. The accuracy of these algorithms depends in part on the accuracy of the user input variables. Most WFOs have used nearby radiosonde or model data as input for the radar, but are increasingly using TAMDAR or other AMDAR data.

WFOs also use TAMDAR to compare with data from radiosondes. The La Crosse, Wisconsin, WFO used some of the first available TAMDAR data on 1 November 2004 to compare to radiosonde data from Minneapolis, Minnesota. The meteorologist initially questioned how dry the air was on the radiosonde sounding. But TAMDAR from the Minneapolis airport supported the very dry reports received from the radiosonde. The dryness of the air was important, as it affected the arrival time of the precipitation. This was reported in the area forecast discussion:

AREA FORECAST DISCUSSION
 NWS LA CROSSE WI
 AFDARX 401 AM CST MON NOV 1 2004

...SHORT TERM...THE NOVEMBER 1ST 00Z 850 MB DEW POINT -36C / AT CHANHASSEN LOOKED INITIALLY SUSPICIOUS WHEN LOOKING AT TRAJECTORIES. HOWEVER...A MESABA AIRCRAFT WITH THE NEW TAMDAR SENSOR AT 04Z HAD A DEW POINT OF -32C IN THE CHANHASSEN AREA. THE ACCURACY OF THIS DEW POINT IS RATHER CRITICAL BECAUSE IT AFFECTS THE INITIAL ONSET OF PRECIPITATION.

6. ACKNOWLEDGEMENTS

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